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Study on High Resolution Transient Electromagnetic Detecting Device Based on FPGA

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Abstract

The transient electromagnetic detecting device is researched in this paper, Firstly, the developing scheme of detecting device system is made based on FPGA control. Secondly, functional circuits such as transmission circuit with fast switch off, data acquisition circuit with high resolution A/D converter, inherent safe explosion-proof power circuit and high speed control technology was develop with large scale FPGA chip and PC104 control. Finally, The result of test show that the developed high resolution transient electromagnetic detecting system is characterized by fast switch off of transmission, high sampling rate, wide dynamic range.

Keywords: transient electromagnetic; FPGA; high resolution; fast switch off

1. Introduction

At present, mine detection methods commonly used at home and abroad include DC electric method, radio penetration method, audio frequency penetration method, Rayleigh wave method, mine geological

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radar, transient electromagnetic method, etc. Of them, transient electromagnetic electric method is an electric method rapidly developed and widely applied since recent years. This method has advantages such as near observation, small volume effect, convenient operation, fast and high efficiency, high sensibility, high horizontal resolution and high reliability, and has been regarded as one of the most prospective geophysical methods for geological exploration. However, because of industrial disturbance in mining areas and limited detection depth, it is difficult to find out underground small water-bearing structures on thesurface. Therefore, to move transient electromagnetic method to underground mines and to conduct near-distance detection of geological structures can enhance detection precision.

Since recent year, it has been continuously tried to apply surface exploration technology of electromagnetic method in underground mines [2-5]. Because there exists inflammable gas in underground mines, the use of transmission system of big power presents hidden hazard for safety in underground mines. Aiming at this problem, some Chinese manufacturers have developed recently electromagnetic sounding devices with attestation of coal mine safety, expecting using them in underground mines. However, the performance of these devices has basically the common indices of surface device, low sampling speed, fewer data channels, can not meet the requirements on shallow detection in underground coal mines. Aiming at this situation, we have carried out research and development of underground transient electromagnetic exploration technology and equipment to accelerate the development of underground in-advance detection techniques, providing necessary technical insurance for safe production of underground coal mines.

2. Principle of transient electromagnetic method

Transient electromagnetic method（TEM）is based on the difference of electric conductivity of rocks, uses not grounded loop or grounded electrodes to transmit primary pulse electromagnetic field, during the gap of primary pulse magnetic field, uses coil or grounded electrodes to observe the secondary electromagnetic field induced by ground turbulence due to induction of the pulse electromagnetic field. Through the distribution of the secondary field in time and space, the variation of electric properties of ground media is investigated to analyze and know related geological issues [3].

The measuring device of transient electromagnetic method consists of transmitting loop and reception loop, working process is divided into three parts: transmission, electromagnetic induction and reception.. On homogenous ground surface with electric conductivity σ, magnetic conductivity μ, a rectangular transmitting loop with area S is laid and supplied jump current I to produce a stable magnetic field(Known as primary field or stimulating field) in the middle of loop and surrounding area.. If the transmitted current is switched off suddenly, the primary field will disappear in the same time, induced electromotive occurs in the interior of conductive geological body located in the magnetic field due to the variation of magnetic flux Φ. According to Faraday's law of electromagnetic induction, when a columnar spiral coil with turns N and sectional area S is put in a magnetic field $B(t)$ which changes with time, induced electromotive force $V(t)$ will be produced in the coil :

$$v(t) = N\frac{d\phi(t)}{dt} = q\frac{dB(t)}{dt} = \frac{N^2 S}{l}\mu_0\frac{dI(t)}{dt} \qquad (1)$$

$$B(t) = \int_t^{\infty}\frac{V(t)}{q}dt \qquad (2)$$

Where $\phi(t)$ is the magnetic flux passing through the coil, μ_0 is vacuum magnetic conduction coefficient, n is the turns of the coil, l is the length of the spiral tube, $I(t)$ is produced induction current, q is the effective area of the reception coil.

Induced electromotive force produces secondary turbulence field (or secondary current) in conductive geological body. Because secondary current changes with time, will produce a new magnetic field nearby (known as secondary magnetic field.). Due to the thermal consumption of the induced current in conductive geological body, secondary magnetic field decays with time approximately by exponential law to form transient magnetic field. Because the decal regularity of induced secondary field is related to the conductivity of ground geological body, the better the conductivity is, the slower the secondary field decays, the poorer the conductivity is, the faster the secondary field decays. The secondary magnetic field is mainly generated from the induced current of conductive geological body, therefore it contains geological information about geological body. Secondary magnetic field is observed through reception loop. To study the regularities of transient field variation with time and to analyze and process observed data can analyze related physical parameters of underground geological body finally reach the objective to detect the distribution of various geological bodies. The working principle of transient electromagnetic method is shown in Fig.1.

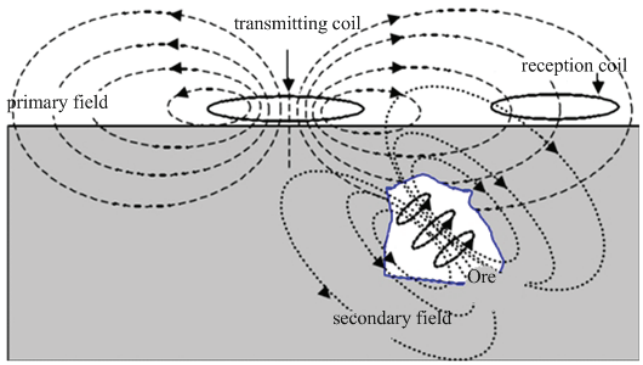


Fig.1. Sketch of the working principle of transient electromagnetic method

3. Overall plan design of mine transient electromagnetic detection system

Mine transient electromagnetic detection system consists of two components: transmission component based on control technology of multiple fast switch off, high sensibility reception component based on A/D conversion of fast speed and high precision. Transient electromagnetic detection system has very strict requirements on time sequence of transmission and reception, very small time difference will influence the reception of transient signals, finally influence the subsequent data interpretation. Therefore, accurate time sequence control system of high precision, fast speed is very necessary for transient electromagnetic system. At present, China made transient electromagnetic reception component uses single board computer, control unit and DSP. But these different ways of control have limitation. Although single board computer is cheap, its speed is slow, control unit has big power consumption and may produce noise, and it is difficult to extract signals of the later stage because of being drowned out by noises. Present existing DSP serial reception units operate by double CPU, their circuit is complex and has high logic requirement, not convenient in usage. The paper adopts control based on FPGA chip [6], it can realize very complicated fast logic, is characterized by being flexible, fast, cheap, anti-copying and remarkable in performance.

The transient electromagnetic detection system developed by the paper includes main control unit, intrinsic safe power, transmitting unit, reception unit, reception probe, A/D converter and displayer. The structural blocks are shown in Fig.2. FPGA and control unit constitute the main control unit to

control the time sequence of the whole system, the synchronization of transmitted signals and received signals, preliminary data processing, data storage and real time display. Transmitting component consists of transmission frame and transmission board, provides dipolar square wave pulse necessary for transient electromagnetic detection. Reception probe and A/D converter as well as their complementary circuits constitute acquisition component of transient electromagnetic data, are used to acquire accurately information of the secondary field and to transmit data.

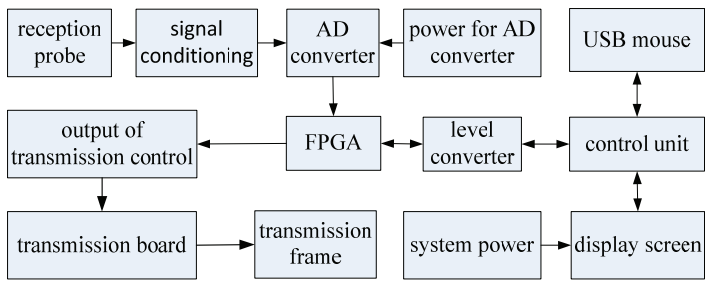


Fig.2. Structural block of transient electromagnetic detection system

3.1. Design of transmitting component based on fast switch off technology

Transmitting component is the important part of the overall transient electromagnetic detection system and the key point of intrinsic safe design. In detection of transient electromagnetic method, the detection depth and precision is not only related to factors such as sampling speed, dynamic range, performance of noise suppression of the acquisition component, but also related to the transmitted current, switch off time, waveform of switch off and moment of the first sampling after switch off. And the equivalent electric induction of the transmitting coil presents hidden hazard for safety. Therefore, the core of the circuit of the transmitting component of the transient electromagnetic requires correct transmitted waveform and short time of switch off of transmission output. The switch off time of most present China made systems is above 200 μs.

The constitution of designed transmitter of the system is shown in Fig.3. Under control of FPGA chip, the transmitting component transmit sequential signals necessary for synchronization of acquired signals to signal-generating circuit to produce dipolar square wave signals, then through isolated driving circuit to fully bridged power circuit to make transmission output. In fully bridged power output unit there is a current sampling circuit for real time monitoring of the transmitted waveform. Fully bridged power output circuit adopts CMOS power triode and interrupting diode. The switch off speed of CMOS tube is very fast, however, there is a transmitting coil, a induction device in transmitting return circuit, high wave voltage L·di/dt will occurs, which may break through MOS tube, probably causing gas explosion in underground coal mines. Therefore it is indispensable to add a protection circuit in transmitting component.

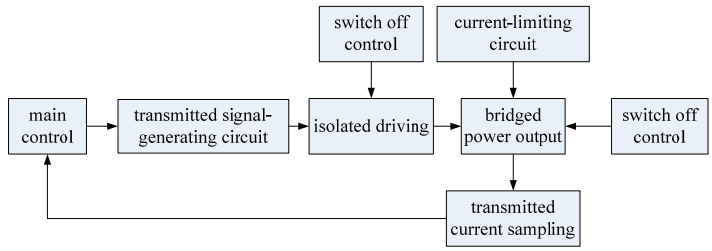


Fig.3. Block diagram of transmission unit

In addition, because signals of earlier secondary transient field correspond to information of shallow layers, in order to get abundant information of shallow layers, there are very strict requirements on switch off time which is controlled at level μs generally. In the system, the transmission frequency is within 25Hz, and it is required to absorb as much as possible overvoltage. Duplex switch off control is adopted: firstly power output bridge adopts combination of electric discharge-stopping RCD buffer circuit and LR circuit to release energy; secondly isolated driving circuit adopts return circuit RC to increase driving voltage drop along slope, finally to realize duplex fast switch off control. Switch off part of power bridge unit is shown in Fig.4.

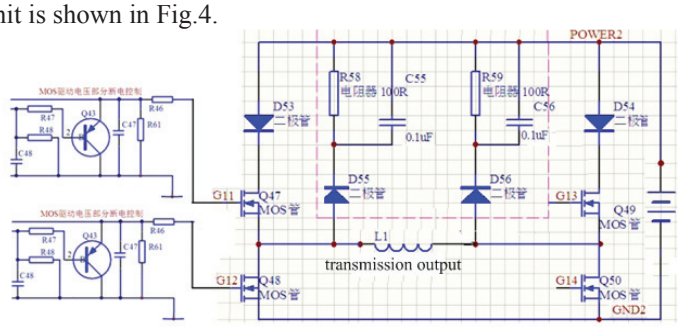


Fig.4. Switch off control of power bridge unit

During twinkling of switch off of transmitted current, transient current induced by L1 passes through diode D55，firstly charges capacitor C55，after being charged the capacitor discharges to resistor R58 to consume energy, after the capacitor finishes discharge, induced current continues to charge the capacitor, the process is repeated to form quasi-resonance shaping circuit, which can not only consume induced current, but also improve linearity of switched off current.. the induced current of the transmitting coil is consumed i9n the transmitting coil and resistor R58, so as to realize fast switch off and meet the requirements of intrinsic safe circuit. The role of diode D53 is to prevent induced current from flowing to power circuit through MOS tube.. In isolated driving unit there is also switch off control as shown in Fig.4. Triode circuit and return circuit RC are added in the end of control of transmitted signals, when transmitted voltage is switched off, the triode conducts under the control of the resistor R48and capacitor C48, capacitor C47 is in short circuit,, therefore the switch off time is greatly reduced.

3.2. Design of high resolution data acquisition component

Transient electromagnetic data acquisition system uses reception coil to detect secondary transient electromagnetic field produced after the transmitted current is switched off. The intensity of secondary transient electromagnetic field decreases with time and weakens rapidly. Therefore, the acquisition of information of secondary transient electromagnetic field needs acquisition system of high precision and fast speed.

The data acquisition component of the system consists of reception probe, signal conditioning component, A/D conversion component, FPGA main control component and control unit, as shown in Fig.5. Its characteristics are: the maximum sampling rate is 2 MHz, simulation signals are input differentially, input voltage range is -2.5 V～2.5 V, single sampling or stacking sampling are optional, stacking number can be set, triggering signal-generating circuit can be equipped, period of triggering signals can be set, PC104 bus interface is supported.

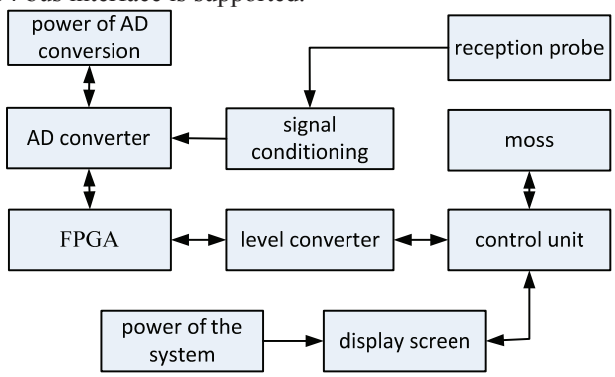


Fig.5. Block diagram of data acquisition flowchart

Transient electromagnetic system has independent A/D sampling circuit of 3 channels with AD7760 as the core, can conduct simultaneous acquisition of 3 channels, for each channel, single sampling or stacking sampling can be selected during operation, the number of stacking can be also set, after data acquisition, data of each channel are transmitted to FPGA chip for processing.

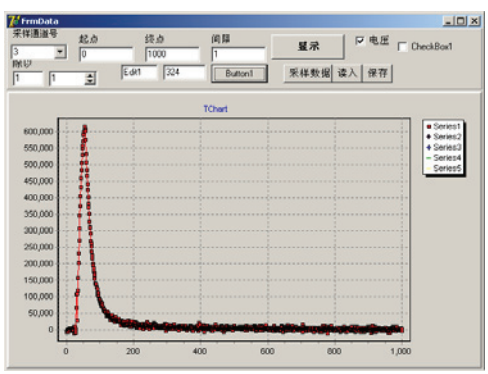
FPGA is mainly used to interface the control unit, generate triggering signals, store sampled data, conduct triple way A/D control and data processing. The role of the control unit is man-machine control interface, through the control unit the operator controls transient electromagnetic system to conduct in-site geological detection, for example, set parameters, issue acquisition order, store and display data transmitted from FPGA. Storage of sampled data is to store sampled data from 3 channels. Triple way A/D control and data processing is to control A/D sample thief through FPGA and to process A/D sampled dat. Triggering signals are order that the system issues for data acquisition.

During data acquisition, FPGA combined with the control unit constitutes the control component. The control unit issues parameters and acquisition orders, FPGA issues the sequence of acquisition orders according to the stacking number and acquisition orders of the control unit. For each independent channel, the reception probe receives signals. The received signals are amplified in signal conditioning circuit and filtered, then enter into high speed A/D converter to digitize. After acquisition data are transmitted to FPGA to stack. FPGA transmits stacked data to the control unit for storage and display.

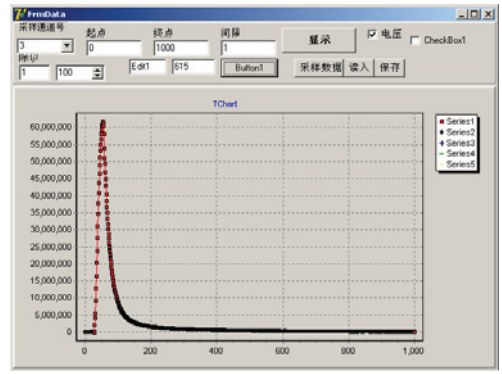
Testing of transient electromagnetic acquisition system

The quality of transient electromagnetic decay curves is the reflection of the performance of acquisition component. The testing adopts respectively 1 stack, 100 stacks and 500 stacks to check the quality of transient signals. Transmission voltage is 7 V，transmission current 2 A,， frequency 25 Hz,

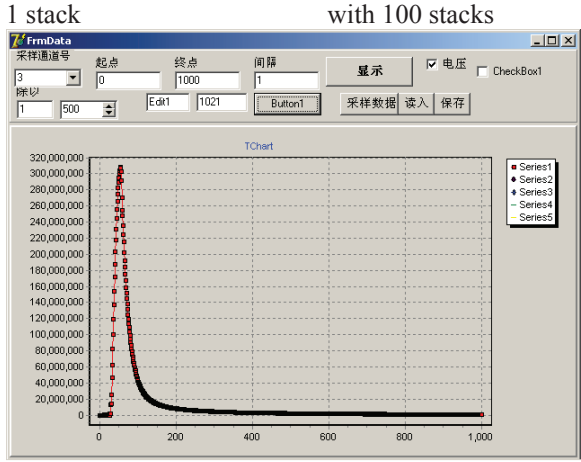
transmission frame 2×2,, rectangular with 8 turns, the reception coil is magnetic probe developed by ourselves, as shown in (a), (b) and (c) of Fig.6. From the figure it can be known that during data acquisition, the higher the stacking number, the better the quality of late transient electromagnetic signals, the smaller the random noise.



(a) Waveform of transient electromagnetic signals with 1 stack



(b) Waveform of transient electromagnetic signals with 100 stacks



(c) Waveform of transient electromagnetic signals with 500 stacks

Fig.6. Waveform of transient electromagnetic signals

Figure 7 shows the results of field acquisition experiment in Bailuyuan in May 5, 2011, apparent resistivity profile after data processing. In the experiment, the interval of detection points was 10 m, 15 points were detected along a straight line. The conditions of the experiment were: 500 stacks, transmission voltage was 7 V, transmission current 2 A, transmission coil 2 m×2 m with 8 turns.

Because Bailuyuan is an area covered by loess, the cover is loess of more than 100 m. the middle is Sancima red soil. The lower is brawn arenaceous mudstone. From figure 7, it can be known that at the experiment site loess is evenly distributed, apparent resistivity increases gradually, coinciding to resistance distribution of the loess layer.

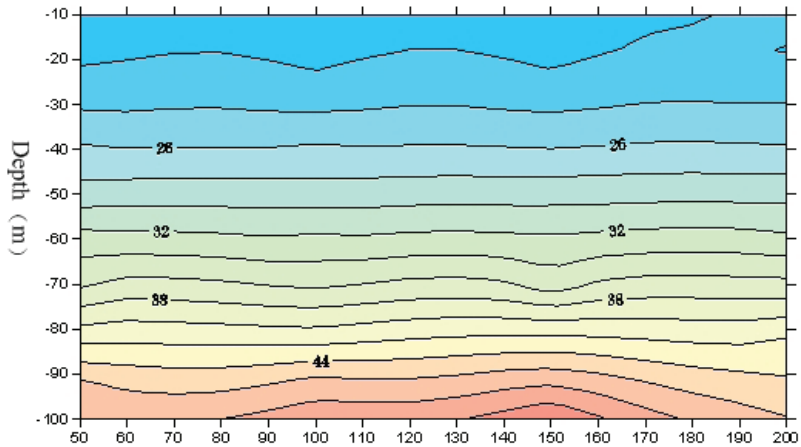


Fig.7. apparent resistivity profile

4. Conclusion

Aiming at the insufficiency of China made transient electromagnetic systems, the paper studied the control technology based on FPGA chip and control unit with FPGA as the main control component. The system consists of data acquisition component with high precision and large dynamic range, current transmission component with fast switch off technology, can meet the requirements for safe use in underground coal mines. it is a transient electromagnetic detection system with advanced performance index. Its transmission switch off time is reduced to 20μs，and its dynamic range of data acquisition is over 120 dB，the minimum sensibility of the reception probe is 0.11 Mv/nT. It can meet the requirements for detection in underground coal mines.

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